NONELECTRONIC COUNTERMEASURES FOR INFRARED GUIDED MISSILES

PART III - USE OF HEAT DECOYS AS COUNTERMEASURES

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ABSTRACT

An analysis of the properties of the ideal heat decoy showed that:

1. The decoy should be dispersed in the air as a shower of hot particles by projection with a suitable fire-arm.

2. Among the possible heat-producing reactions, combustion reactions are the most suitable and, in particular, the combustion of carbon offers the most promise.

3. The duration of the decoy should be about 30 seconds, to be controlled by adjusting the rate of reaction and particle size of the decoy substance. The preferred decoy should comprise a reaction mixture which can be ignited after dispensing.

Some preliminary experiments are described and previous work reviewed.

From the analysis it is concluded that future experimental work should be concentrated on the type of heat decoy comprising a canister filled with carbon granules impregnated with an oxidizing agent and ignited either by a burster charge or, if necessary, by some spontaneously inflammable material coating the granules. The number of canisters for each application of the countermeasure depends on the size of the ship to be protected.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

NONELECTRONIC COUNTERMEASURES FOR
INFRARED GUIDED MISSILES

PART III - USE OF HEAT DECOYS AS COUNTERMEASURES

INTRODUCTION

The first of this series of reports (1) analyzed the problem of nonelectronic counter-measures against infrared guided missiles, defining the problem in general and describing the operation of the "Dove Eye." This report will deal with the heat-decoy type of countermeasure.

Among the possible countermeasures against infrared guided missiles, heat decoys would appear to be the most versatile and dependable. Camouflage, thermal noise sources, and electronic countermeasures operate by reducing or negating the guidance given to the missile by the DOVE. In use, the missile is dropped so as to require a minimum of guidance, the DOVE being used essentially to apply small corrections to the flight of the missile. Therefore there remains a substantial possibility that the missile will fall on or near the target even when the DOVE is rendered inoperative. More desirable is a countermeasure which would actually depend on the heat-homing principle to decoy the missile away from the ship by offering a more attractive target. Under this heading there then remain FLOOR and heat decoys.

FLOOR has inherent disadvantages which in some degree render its use unsatisfactory (2). On the basis of the functional criteria, for example, the use of FLOOR is, at best, a marginal technique, i.e., the protection offered is not much beyond adequate, leaving only a small margin of safety. Further, there are many conditions (cloudy or "warm" skies, possible solar conditions, etc.) under which the protection offered will be inadequate, so that FLOOR is a satisfactory technique only a part of the time. On the basis of the tactical criteria, the use of FLOOR suffers because of (1) the reduction in maneuverability of the ship being protected, and (2) the time required for it to be brought into action. Heat decoys, on the other hand, can operate under any atmospheric or light conditions under which a ship might be vulnerable to infrared guided missiles. Moreover, heat decoys can be constructed to be brought into action rapidly and at any arbitrary interval so that the ship while pursuing its normal course or taking evasive action can have a decoy in position.

In Part I (NRL Report 3703) it was shown that the functional criteria of the ideal heat decoy require that it emit as much or more radiant energy (radiant flux per total area) in the 8-12 mu region of the spectrum as the ship to be protected; it should have an area of about the same magnitude but not exceeding that of the ship, the optimum size depending on the resolving power of the homing device; it must remain near enough to the ship so that both are in the field of view of the missile during the effective interval of activity of the latter; it must persist a sufficient length of time for the missile to operate effectively throughout its whole interval of activity. Thus, ideally, the decoy presents to the missile a more attractive target than the ship.

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Although attention here will be focused on decoys as defined above, it must be borne in mind that heat forming materials can be dispersed in small patches which introduce a background of thermal noise into the field of view of the missile thus reducing its power of discrimination.

With the exception of metals, most surfaces (3) have emissivities (fraction of black-body emissive power) of more than 0.65. It will therefore be assumed here that the emissivities of the proposed nonmetallic countermeasure materials are roughly the same as that of a ship, which is a painted and therefore nonmetallic surface. This assumption implies that as long as the surface of the countermeasure material is at a higher temperature than is the ship's surface, the emissive power of the former will be larger. Evidently, if the decoy presents a compact surface to the missile, it need be only a few degrees hotter than the ship's surface to produce adequate decoying signals, provided the total areas involved are comparable. If the decoy, however, is in the form of a cloud of particles which presents a surface containing holes, the particles would need to be at some higher temperature since the total energy emitted is proportional to the projected area. In general it can be said that the decoy should develop as high a radiant temperature as is compatible with the tactical criteria.

CRITERIA FOR THE IDEAL HEAT DECOY

The functional criteria for heat decoys depend on the sensitivity, resolving power, and field of view of the homing device. The tactical criteria, on the other hand, result from the exigencies of practical military considerations. Although the criteria for the ideal counter-measure should apply to all methods of countermeasuring, some of these are automatically fulfilled with a given type of countermeasure and therefore need not be considered in choosing between two candidates within the given type. Therefore, the following list contains some tactical criteria which apply specifically to heat decoys and need to be considered in evaluating them. The list is not intended to be exhaustive but the most important criteria are represented.[1]   The heat decoy should:

   (a) Not reduce the maneuverability of the target vessel;

   (b) Be capable of being brought into action very quickly;

   (c) Require a minimum of personnel and equipment to operate;

   (d) Not place neighboring vessels in jeopardy;

   (e) Comprise noncritical and preferably cheap materials which can be produced in large volume;

   (f) Be safe to prepare and handle;

   (g) Include air and/or water as one of the reactants to reduce the bulk and weight of materials to be carried and dispersed.

Other desirable features, but of lesser importance, are that the decoy leave no non-volatile floating residue to indicate that a vessel has been in the vicinity, and that the decoy produce no visible light. It is, however, debatable whether the presence of light will

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[1] This list was worked out in conference with S. Snyder, Project Engineer, Section Re9d, Bureau of Ordnance.

measurably reduce the security of a vessel, since its position can be presumed to be known to the enemy once it is under attack.

The diversity of the tactical criteria is such that if compatibility with all of them is required, it may very well prevent reaching a solution. Therefore it must be understood that some compromise will have to be made with any or all of the criteria in order to realize a practical solution. Obviously not all are equally susceptible to compromise. For example, little reduction can be made in the requirement that the countermeasure be brought into action quickly. On the other hand, the requirement that the countermeasure react with air or water is not necessarily rigid. Each criterion must be accorded a suitable weight in judging candidate materials.

DISPERSION OF HEAT-FORMING MATERIALS

Methods of dispersing heat-forming materials can be conveniently divided into three groups: (a) Those which are laid down on water, (b) those which are released under water and float to the surface, and (c) those which are projected into the air. Group (a) includes foams, "slicks" or floating films of material lighter than water, and finely divided particulate materials which can be rendered hydrophobic (not wetted by water) to make them float. Group (c) can include any gas, liquid, or solid which can be made to remain suspended for at least as long as sensible heat is being produced. Group (b) includes materials similar to those in group (a) but which in addition can be dispersed by injection into the wake at the ship's propellers. In this group, however, materials reacting with water are ruled out. In this case the bubbles could be stabilized by injection of a foaming agent into the wake. All three types might use water or air as an ingredient in the reaction.

Dispersions on or under water can be accomplished by spreading with a nozzle or by throwing with a firearm in a manner similar to depth charges. Dispersion in air can be accomplished by throwing with a firearm. In view of the large area which must be covered to produce an adequate decoy and the limited time available to bring the decoy into full activity, it is doubtful whether any countermeasure involving spraying through a nozzle can be adequate. Another serious disadvantage of this method is the hazard to the ship introduced by spraying very reactive or inflammable materials from it. But the use of containers which can be projected and then burst appears to be applicable to nearly every type of heat-forming material and has the additional advantage of introducing the fewest storage problems. If necessary, multiple bursts can be used to insure coverage of an adequate area.

HEAT-PRODUCING REACTIONS

The temperature to which a body will rise during a chemical reaction is a complicated function of several variables, some of which are not readily determinable. Broadly speaking it will depend on the rate at which heat is produced, the specific heat of the reacting mass, and the rate of heat dissipation. The rate at which heat is produced depends on the total free energy of the reaction and the rate of reaction; the rate of heat dissipation is a function of the temperature difference between the reacting body and its environment, the specific heat of the environment, and the rates of conduction and radiation of the reacting mass. In turn, the latter rates depend among other things on the ratio of surface to volume of the reacting mass. Not all of these variables can be controlled. For example, the specific heats of water and air are fixed. It appears that for the purpose at hand, attention should be fixed on control of the total available free energy, the rate of reaction, and the state of dispersion of the reacting mass. Limitations are imposed on the controls by two requirements: the state of dispersion must be such that a large area must be uniformly covered

by a reasonable bulk of reactants, that is, a bulk which can be conveniently projected; the reaction must deliver a substantial amount of energy in the 8-12 mu region. The latter requirement essentially limits suitable reactions to those which produce hot liquid or solid surfaces with high emissivities.

For the purposes of this problem it will be advantageous to consider the amount of heat generated by a given weight of material rather than on a molar basis. Therefore the "efficiency" of a reaction will be defined as the number of kilocalories (kcal) produced by the reaction of one gram of material. The quoted weight will include only the chemically active material carried and dispersed by the ship without regard to the amount of air or water necessary to effect the given reaction.

Methods of producing heat can be divided into two broad classes: changes in physical state and changes in chemical state. Others such as mechanical, electrical, and nuclear methods need not be considered for obvious reasons. Changes in physical state that produce heat are exemplified by changes in crystalline form, solution, condensation, freezing, etc. In general the amount of heat produced by such changes is one or more orders of magnitude smaller than the amount of heat produced by chemical changes for a given weight of material. They can therefore be disregarded for the purpose at hand. Chemical changes that are potentially useful for countermeasuring can be subdivided roughly into the following classes: oxidation, metathesis, hydration and hydrolysis, neutralization, and decomposition. Reactions involving metathesis produce relatively small amounts of heat; the efficiency of neutralization reactions is likewise quite low; and decomposition reactions are difficult to control in rate. Tables 1, 2, and 3 give the efficiencies of some of the reactions covering the remaining classes which are most promising for the purpose of countermeasures. Tables 1 and 2 are given in order of decreasing atomic or molecular weight, and Table 3 in the order of decreasing efficiency.

TABLE 1
Heats of Solution of
Various Compounds

Compound	kcal/gm
LiH	3.90
Li_2O	1.04
NaH	1.08
Na_2O	0.91
SO_3	0.49
K_2O	0.80
$AlCl_3$	0.60
$TiCl_4$	0.30
PCl_5	0.62

TABLE 2
Heats of Combustion of
the Elements

Element	kcal/gm
$H \rightarrow H_2O$	34.15
$Li \rightarrow Li_2O$	10.20
$B \rightarrow B_2O_3$	12.95
$C \rightarrow CO_2$	7.85
$Na \rightarrow Na_2O$	2.16
$Mg \rightarrow MgO$	6.00
$Al \rightarrow Al_2O_3$	7.20
$P \rightarrow P_2O_5$	5.90
$S \rightarrow SO_2$	2.16
$K \rightarrow K_2O$	1.10

TABLE 3
Heats of Combustion of
Compounds and Other Substances

Compound	kcal/gm
Acetylene	12.0
Heptane	11.5
Gasoline	11.5
Crude Oil	11.0
Fuel Oil	10.5
Benzene	10.0
Asphalt	9.5
Vegetable Oil	9.5
Ether	8.8
Amorphous Carbon	8.0
Trinitrotoluene	3.7
Nitrocellulose (11.3% N)	2.6
Nitroglycerine	1.6
Gunpowder	0.8

Table 1 lists heats of solution which include heats of hydration and/or hydrolysis. It will be noted that every substance listed reacts with water either by hydration or hydrolysis. The resulting hydrated materials then dissolve in a large excess of water. The values of the heats of solution as given then are the sum of the heats of hydration or hydrolysis and solution. True heats of solution as pointed out above are very small.

Several features of the tables are noteworthy. It is immediately evident that the efficiencies of the various reactions tends to improve, the lower the molecular, or the atomic weight of the reacting element. In particular, the best efficiencies in Table 1 are associated with lithium compounds. It is evident from inspection of the tables that heats of hydration are in general only a small fraction of heats of combustion. This fact need not entirely rule out the reactions of Table 1 since it has been shown (4) that FS smoke which contains SO_3 as an important ingredient produced a thermal signal of the same order of magnitude as a medium sized ship. It can be concluded that materials delivering as little as 0.50 kcal/gram can be useful as a heat source even when dispersed as finely as FS smoke. Titanium tetrachloride (the principal ingredient in FM smoke) is reported, (4), however, as having produced thermal signals which were considerably smaller than ships' signals although its heat of reaction is about 0.30 kcal/gram.

Inspection of Tables 2 and 3 reveals that the most promising reactions for producing heat efficiently are combustion reactions. Again it is true that low atomic or molecular weight materials are associated with the best efficiencies. Indeed the heat of combustion of hydrogen is so high that materials containing hydrogen in large proportions (hydrocarbons such as heptane, oil, gasoline, for example) have uniformly high efficiencies. It should be noted that materials often mistakenly associated with high heat production such as nitro-cellulose or gun powder have efficiencies which are only small fractions of those associated with the hydrocarbons. This is due to the presence of oxygen in the former. That is to say, they are already partly oxidized.

Some of the reaction products of Table 2 will hydrate in moist air with an additional evolution of heat but when the heat of hydration and solution is added to the heat of com-bustion, only a small percentage change results in the total heat produced. For example, the heat of combustion of lithium is 10.2 kcal/gm. If the resultant lithium oxide is then dissolved in water, the sum of the heats of reaction and hydration increases to only 10.7 kcal. A somewhat greater precentagewise change is produced for the heavier alkali metals. Sodium burning to Na_2O has a heat of 2.16 kcal/gm. The resultant solution of Na_2O in water yields another 0.68 kcal.

In view of the fact that a substance with an efficiency of 0.50 kcal/gm has been found to give a thermal signal comparable to that of a ship even in a state of high dispersion, it can be said that abundant heat for the present purpose can be obtained from any of the reactions listed in the tables. The choice of reaction will then depend on how well the reaction can be initated and controlled in rate, and how well the materials involved lend themselves to handling and dispersion.

RATES OF REACTION

As pointed out above, the heat of reaction alone cannot be used as a measure of the temperature reached by the reacting body. The thermite reaction, for example, although producing a total amount of heat far smaller than an equal weight of burning gasoline, reaches temperatures which melt iron because the heat is all produced in a matter of a second or two. In the countermeasure contemplated here it is necessary that the reaction rate be held to a level at which high enough temperatures are reached to give signals greater than the target vessel, but not so high that much of the energy is wasted in visible light and/or the reaction is over in a very short period of time. Ideally the temperature reached by the reaction mixture should be just above that necessary to maintain combustion.

There are several ways of reducing reaction rates, such as withdrawing heat from the reaction mixture or making access of air to the reaction mixture (in the case of a com-bustion) difficult. A method which promises to be most easily controlled, however, is to

introduce an inert diluent into the reaction mixture. If the diluent is properly chosen, it will have a twofold function. First, it will absorb heat from the reaction mixture without itself contributing to the heat of reaction; and, second, once hot it will act as a reservoir of heat which will continue to produce radiant energy for an appreciable time after the main reaction is over.

Not all reactions are equally amenable to dilution. The thermite reaction, for example, has so high an activation energy, that much reduction in temperature will stop the reaction. In one experiment thermite was diluted with 20 percent by weight of diatomaceous earth and the reaction failed to propagate more than a few mm beyond the magnesium ribbon fuze.

A promising possibility that requires consideration is the "fortification" of mixtures that do not continue burning after the source of ignition is removed. For example, cellulose or dense carbon will not always continue to burn after ignition, particularly if they are very compact so that access of air is limited. They can be made to burn with controllable vigor by impregnating them with varying quantities of some oxidizing agent such as sodium nitrate. In a series of experiments, carbon granules were slurred with a solution of sodium nitrate and the slurry dried. The resultant mixture, cast into cakes 2 inches in diameter and 1/2 inch thick, could be ignited, and burned quietly for as long as one-half hour. The surface was quickly covered with a grey ash which obscured the initial dull red glow after a minute or so, although the cakes continued to produce sensible <u>radiant</u> heat for at least one-half hour.

A typical formula was as follows:

Carbon (Wyex beads) 100
Sodium Nitrate 20
Glue 2
Water . . . . qs

The purpose of the glue was to cement the particles together and to prevent the cake from crumbling. Clearly, if the above mixture were dispersed as discrete particles so that air could have access to all sides of each particle, the reaction would be over much sooner.

AMOUNT OF MATERIAL NECESSARY FOR A HEAT DECOY

In order to estimate the amount of carbon, say, which will be required to form a decoy, a rough calculation can be made as follows: To a good approximation carbon can be considered a black body whose oxidation occurs at dull red heat. At dull red heat, the color temperature (the same as the true temperature for a black body) is about 600^0 C, say 900^0 K. Using the classical black body radiation curves (5) the radiation in the 8-12 mu region can easily be calculated as about 300 watts/ft^2. This result is to be compared with the 300 watts/ft^2 measured (6) as the radiation in the 8-13 mu region emitted by burning benzene. If the ship is considered a black body, its surface as 300^0 K should radiate in the 8-12 mu region about 4 watt/ft^2 relative to background. This is in good agreement with the radiation from a battleship measured as 290 KW (7) which for a 60,000 ft^2 ship comes to 5 watts/ft^2.

This means that a sheet of carbon at dull red heat one-seventyfifth the area of a ship will give an equal thermal signal (800 ft^2 ≙ 60,000 ft^2 in subtended area). This sheet can be broken up into particles 1 mm square, say, and spread out to match the ship's area and shape. No heat homing missile should then be able to distinguish between the ship and the layer of particles. If the particles are 1 mm thick, the total volume of carbon necessary to make a single layer of particles is about 3 cubic feet. Since the particles will not be able

to be dispersed so uniformly, some volume larger than that given above will be required, the exact amount depending on how efficiently a bomb burst can be made to spread the material.

Similar calculations can be made for other materials but some knowledge is necessary of the color temperature of the reaction mass and its emissivity.

DURATION OF COUNTERMEASURE

An estimate can be made of the minimum length of time available for dispensing the countermeasure and the duration of its subsequent activity by considering the time of fall of the missile, the interval during which the homing device is active, and the particle size and shape of the countermeasure material. A simplified and extreme case will be presented which assumes that the countermeasure is dispensed at the moment the missile is released from the plane. In practice the duration of a single heat decoy may be necessarily greater if the ship dispenses it in anticipation of an attack. On the other hand, if the decoys can be dispensed at frequent enough intervals, the periods of activity may overlap thereby reducing the duration requirement. In general, it can be said that the duration should be as long as possible to reduce the number of decoys necessary during a single attack and to minimize the timing problems involved in dispensing successive decoys.

The missile will be dropped from 20,000 feet, say, but the DOVE is "opened" only after its fall approaches vertical so that it can no longer see the horizon. This occurs at 8,000-12,000 feet.[2] Assuming the missile to suffer no air resistance, and to be released with no significant vertical velocity component, the time of fall can easily be calculated from $d = 1/2\ gt^2$ where $\underline{d}$ is the distance, $\underline{g}$ the acceleration of gravity, and $\underline{t}$ the time of fall. Thus the total time required for the missile to fall from 20,000 feet to sea level will be 35 seconds. If the DOVE opens at 10,000 feet, the time used during the first portion of the drop will be 25 seconds. This means that from the time the missile is dropped, the ship has 25 seconds to bring the decoy into full activity and if everything is timed exactly right, the duration of the decoy should not be less than 10 seconds. To the figure of 10 seconds must be added any anticipatory time. This calculation gives only the order of magnitude of duration of a decoy. A considerable safety factor would be highly desirable and a decoy with an active life of, say, 30 seconds would probably be adequate from most standpoints.

In addition to the limitation imposed by the length of time during which a particle of given size will produce heat, there is the additional limitation due to the length of time it takes a particle to fall a given distance. Stokes' law governing bodies falling through viscous media can give an estimate of the length of time of all of small particles. For the limiting case we will assume the particles to be spherical with a density of 2.0. It is unlikely that any materials useful for heat decoys will have much larger densities. For spherical particles (8)

$$V = \frac{2\ g\ r^2(d-d')}{9\ \eta}$$

where d and d' are the densities of the particle and air respectively, g is the acceleration of gravity, r the radius of the particle, η the viscosity of air at 25° C (3) and V is the rate of fall in centimeters per second. Since the density of air can be neglected, the equation reduces to:

[2] These figures were suggested by S. Snyder, Project Engineer in Section Rc9d, BuOrd.

$$V = \frac{2 \times 980 \times r^2 \times 2}{9 \times 187 \times 10^{-6}} = 2.33 \times 10^6 \, r^2 \cdot$$

Table 4 lists a few values of V in the range of interest here in terms of the particle diameter.

TABLE 4
Rate of Fall of Spherical Particles (Density = 2.0)
In Air at 25° C

Rate of Fall	Distance of Fall in 30 Seconds	Particle Diameter
1000 cm/sec	1000 ft	0.42 mm
750	750	0.36
500	500	0.30
400	400	0.26
300	300	0.22

It must be emphasized that this calculation represents the extreme case. In practice the permissible diameters may be substantially larger for the following reasons: The density is unlikely to be as high as 2.0; but more important is the fact that the particles will deviate in form from smooth dense spheres thereby increasing air resistance. In addition there will be the factor that the particles are producing heat, causing updrafts in their immediate vicinity, again tending to decrease the net rate of fall. Finally, the particle will decrease in size and weight as it burns, thereby decreasing the net rate of fall. The latter condition holds only for particles whose main component is a fuel and whose reaction products are gases. For particles which produce heat by hydration, the weight will increase. Unfortunately, at present no estimate can be made of these factors, but a few generalizations are possible as follows:

(a) The order of magnitude of particle size for a decoy which will stay in the air about 30 seconds is about 1 mm in diameter if the particles are first projected to a height of 500 feet.

(b) To increase the duration or decrease the height of projection for a given duration, the particles should be of such a shape as to offer the greatest resistance to fall. For example, flat discs might be suitable.

(c) The decoy should preferably comprise particles which lose size and weight as the reaction proceeds thus permitting greater leeway in the original size.

It is desirable to increase the original particle size to a maximum to insure that the particles are not entirely consumed before they fall into the sea. Particles of carbon, say much smaller than 1 mm in diameter, may be completely burned in less than 30 seconds, particularly if they are porous.

INITIATION OF HEAT-PRODUCING REACTIONS

Insofar as the behavior of a heat decoy after dispensing is concerned, a self-initiating reaction would be advantageous. In this way fuzes and matches can be avoided. Among the reactions listed, the following will start spontaneously on contact of the reactant with air and/or water: All the compounds of Table 1; in Table 2, Li, P, K, Na. It is, in addition, possible to use mixtures where a spontaneously reacting material is added to a fuel to act as a source of ignition. Examples of this type of mixture are phosphorus solutions in carbon disulfide; pyrophoric (self-igniting in air) mixtures of potassium with carbon (9); or an alkali metal dispersed in a hydrocarbon vehicle. Other substances have to be ignited by raising their temperature locally to the ignition point by external means, the reaction then proceeding to completion as long as fuel remains. This type of reaction is exemplified by gunpowder and any of the appreciably volatile hydrocarbons. Still other substances such as crude oil and asphalt require relatively large amounts of preheating the whole mass before combustion will continue once started and are thus ruled out on that account.

One serious objection must be recorded to the spontaneously igniting mixture. A significant hazard is involved in their storage. They would become dangerous if a container were accidentally ruptured or were defective, especially since neither water, CO_2, nor CCl_4 can be used to extinguish fires caused by the reaction of these materials. The mixtures which must be ignited are in general less hazardous and should be able to be handled by standard ordnance procedures.

SMOKES, FOAMS, AND SLICKS

Smokes, foams, and slicks can be made to act as heat decoys. In the following, the arguments pertaining to foams apply generally to slicks also.

Hot smokes such as FS, WP, and PCl_5 have been reported to emit one to two times the amount of radiant energy in the 8-12 mu region as a medium sized naval vessel (10). But it was also mentioned that the duration of the thermal signal was short (less than 10 seconds). This is, of course, due to two facts: (1) The particle size of the smoke is very small so that the reaction is over very quickly; (2) the amount of heat originally available is small since (with the exception of WP) the reaction is hydrolytic. The short duration of the thermal signal would make smokes difficult to use as heat decoys. It is not evident at this time how this situation could be remedied. Another unfavorable factor is that the hydrolytic smokes produce corrosive and perhaps toxic vapors, while WP is a serious fire hazard. (It has been used against personnel in trench warfare.) In general, it appears that hot smokes offer little promise as potential heat decoys.

Foams can act by carrying heat producing materials or by reducing the emissivity of the water surface as does FLOOR. The basic disadvantages inherent in all decoys dispensed on the water surface apply here. The combination of requirements that the decoy be brought into activity quickly and not limit the maneuverability of the vessel effectively rules out the use of large discrete patches of foam. There remains, therefore, only one way of dispersing foams, i.e., to form a continuous patch on the surface of the sea, either by throwing over the side a continuous spray through a nozzle, thus producing an elongated patch running parallel to the vessel's course or by utilizing the wake to produce and/or carry the foam. It is obvious that such operations must be carried out considerably in advance of the time a missile is dropped. Furthermore, it is not quite clear how DOVE would react when confronted with a compact signal produced by the vessel together with a decoy signal one dimension of which is very large compared to the other.

Foams can be made to carry heat-forming of two kinds, i.e., those which react with water and those which react with air. It is unlikely that an adequate signal of useful duration can be produced by a reaction at the water surface. The high specific heat and heat-conductivity of water will draw off the heat rapidly enough so that very little temperature rise can be expected. In view of the area that needs to be heated, the required duration, and the temperature rise needed (considering that the decoy needs to be hotter than the ship's surface), no practically possible quantity of known materials satisfying all the requirements can be visualized. Another damaging factor is that any thermal radiation generated will have to penetrate a layer of foam before it can reach the DOVE. In any case, it is theoretically impossible that any reduction of the emissivity of the water surface by a foam can ever be as great as the reduction provided by an ideal FLOOR, and it has already been shown (2) that ideal FLOOR cannot be effective under certain atmospheric conditions.

Substances which react with air appear to offer more promise, but are still likely to be inadequate. In this case the reaction should take place mainly at the air-foam interface so that a substantial part of the radiant energy is available. Furthermore, the foam may act to insulate somewhat the reacting ingredients from the water surface, thus helping to attain higher actual and radiant temperatures. Elemental phosphorus cannot be used in this connection since it will not burn when wet. All the other substances of Tables 1, 2, and 3 which react spontaneously with air also react with water and would thus uselessly dissipate much of the available heat. Phosphine mixed with P_2H_4 is a possibility but must be handled with great care because of its tremendous toxicity.

All things considered, it appears that foams or slicks, even if made to carry heat-forming materials, offer less promise as a countermeasure to heat-homing missiles than other materials discussed elsewhere in this report.

SOME PRELIMINARY EXPERIMENTAL RESULTS

A Bureau of Ordnance secret report (10) summarizes among other things the preliminary work done on heat decoys prior to this project. The summary quotes some of the data and conclusions derived from various sources. Some of these that are of interest here are as follows:

1. Depth bombs containing 300 lbs of Napalm gelled gasoline with sodium igniters burned as long as 60 seconds giving radiant fluxes as high as 13.5 times that of a ship.

2. One such bomb might protect all but the largest ships; four would be sufficient for the largest battleship.

3. Some very sketchy data on hot smokes (FS, WP, PCl_5) show that for short periods of time such smokes can produce signals as large as ship signals (see preceding section).

No really valid judgements can be made from these experiments except that combustion reactions involving compact masses produce much more heat than diffuse hydrolytic or hydration reactions such as are involved in the preduction of smokes.

In addition to those on thermite and carbon-sodium nitrate mixtures mentioned above, a few other preliminary experiments were also performed. A few sodium dispersions in oil (obtained from Dr. W. S. Calcott of the DuPont Company) were spread on water. The oil-metal mixture in every case was such that the oil did not ignite, the sole source of heat

being the reaction of sodium and water. It was found that almost no sensible radiant heat was produced by the reaction, presumably because the high specific heat and heat-conductivity of the water drew off the heat very rapidly. Although this situation could undoubtedly be improved by altering the mixtures, it probably could not be sufficiently improved to warrant pursuing investigations in this direction any further.

A more promising mixture was that obtained by preparing alloys of potassium and carbon. Carbon will "absorb" about 30 percent by weight of potassium metal. This "alloy" is pyrophoric (becomes spontaneously incandescent in air). The storage problem might be a serious one, however. The alloy must naturally be prepared and kept in an oxygen and water-free atmosphere. Under laboratory conditions, a carefully stoppered bottle did not offer sufficient protection to prevent air and/or water from getting into the bottle and killing the activity. Sealed metal containers might, however, be suitable.

SOME POSSIBLE HEAT-FORMING MIXTURES

The heat-forming reactions in Tables 1, 2, and 3 were listed to exemplify some of the more energetic reactions theoretically available for countermeasures. This section will list some of the promising mixtures as they might be used in practice. For simplicity, in those places where a fuel and an igniter are mentioned, dense carbon will be considered as the fuel, although it might turn out that some other material or form of carbon is more suitable. Among the possible fuels could be mentioned petroleum coke, various carbon blacks, paper pulp, peat moss, bagasse (cellulose residues from sugar processing), etc.

Paper pulp and bagasse would probably burn most slowly giving off the least total heat because they already contain oxygen. The only advantage in using them might come from some factor involving compounding or dispensing the mixtures. Petroleum coke is dense and nearly ashless and would require less igniter because of its small porosity but on the other hand it might not continue burning after the igniter is exhausted. Channel and other blacks have the disadvantage that they are friable and have such small ultimate particle size. However, aside from the difficulty of maintaining a large particle size during dispersion, these blacks offer the most promising source of fuels.

The spontaneously igniting mixtures are hazardous, but if this factor can be adequately controlled, the following are promising mixtures:

1. Yellow phosphorous alone, or carbon impregnated with a solution of phosphorus in carbon disulfide.

2. Pyrophoric graphite (potassium-graphite "alloy").

3. Sodium alone or as a dispersion in naphthalene or other solid or liquid that can act as a fuel. (Naphthalene burns with dense black smoke.)

4. Carbon impregnated with aluminum triethyl.

5. Sodium hydride, alone or with carbon.

Other mixtures are possible but seem to offer no a priori advantage over the above. These mixtures are distinguished by the fact that all of them contain only abundantly available and noncritical materials.

Better than the spontaneously ignitable mixtures from the safety standpoint, and apparently not less satisfactory from other considerations, are the following which need an

external igniter. Conventional ordnance procedures are probably available for such ignition.

1. Mixtures of carbon and oxidizing agents. This kind of mixture can be considered to be a modified black gunpowder whose rate of burning can be controlled by varying the ratio of carbon to oxidizing agent.

2. Carbon and/or carbon-oxidizing agent mixtures covered with a thin layer of gun cotton or other easily ignitable and vigorous combustion mixture.

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that the preferred heat decoy should comprise some kind of bomb capable of being projected and burst in air, and containing a solid combustible mixture ignited during the burst and burning at dull red heat. In particular, items 1 and 2 immediately above appear to have the widest compatibility with the operational and tactical criteria. Comparison with the individual criteria listed earlier shows this clearly.

(a) The maneuverability of the ship is at a maximum since a decoy can be placed opposite the ship as frequently as is necessary.

(b) These mixtures can be dispersed in shells or bombs and thus brought to activity quickly.

(c) They should require no more personnel or equipment than that necessary to operate a single anti-aircraft battery, for example.

(d) No toxic and little or no corrosive fumes are produced. A slight fire hazard exists to neighboring vessels but no more than that created by cinders from the stack, for example.

(e) All materials necessary are cheap, abundant, and noncritical in wartime.

(f) Preparation and storage should be less hazardous than preparing and storing gunpowder, for example.

(g) Air is one of the reactants.

In addition there are the desirable features that no nonvolatile floating residue will be left and that nearly all the radiant energy is produced in the red and infrared spectral regions. The high emissivity of carbon insures that the radiant energy will be near the theoretical maximum for the given temperature.

Although final design of the actual operating heat decoys should properly be in the hands of ordnance and pyrotechnic experts, the ideal decoy is visualized somewhat as follows: A shell or cannister containing about 1 cubic foot of carbon granules properly impregnated to take fire on burstings; the bursting charge designed to ignite the granules and disperse them to an area of perhaps sixty feet by 100 feet; about six shells (for the largest ships) to be projected and burst simultaneously 300-500 feet in the air, perhaps 100 yards to the side and slightly forward of the ship, the bursts to just touch each other and form a straight line as shown in Figure 1. For smaller ships, fewer shells would be needed, the total area of the decoy always being kept somewhat smaller than the ship.
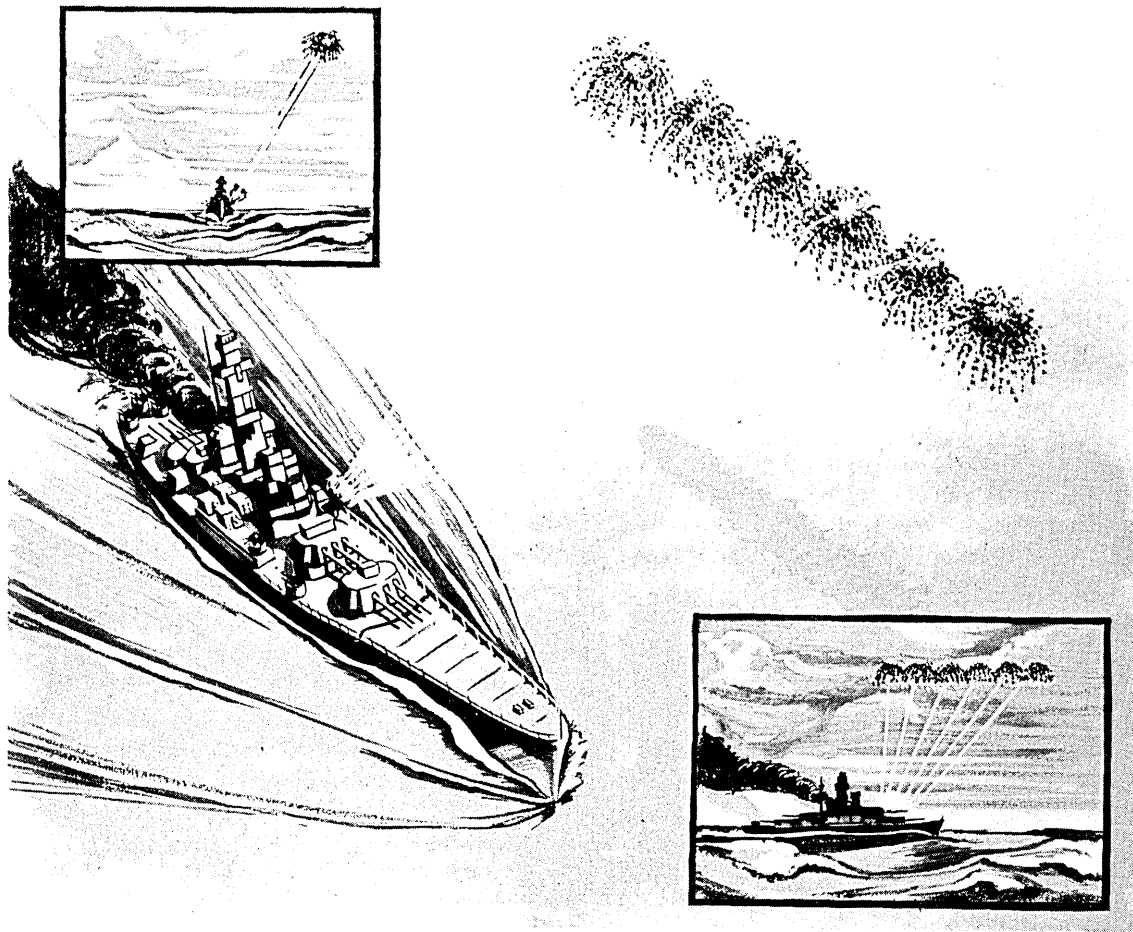
Figure 1

In this report consideration has been given to countermeasuring free-falling missiles. It should be evident, however, that the heat decoy contemplated here should have possibilites as a countermeasure for glide-angle missiles as well.

It is recommended that:

(a) Future laboratory experiments emphasize carbon-igniter mixtures to discover the optimum particle size, the best type of fuel, and the most efficient and fool-proof igniters.

(b) Investigation of other types of heat decoys, in particular the self-igniting mixtures, be carried along at the same time to provide possible alternatives.

(c) Efforts be concentrated on decoys which are projected into the air since foams and slicks appear to hold little promise.

* * *

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